8.3 Applications of Magnetic and Electric Fields

SECTION EXPECTATIONS

- Define and describe the concepts related to electric, gravitational, and magnetic fields.
- Predict the forces acting on a moving charge and on a current-carrying conductor in a uniform magnetic field.
- Determine the resulting motion of charged particles by collecting quantitative data from experiments or computer simulations.
- Describe instances where developments in technology resulted in advancement of scientific theories.

KEY TERMS

- particle accelerator
- mass spectrometer
- cyclotron
- synchrocyclotron
- betatron
- linear accelerator
- synchrotron

In previous science courses, you have probably read that the mass of an electron is 9.1094×10^{-31} kg and that the mass of a proton is 1.6726×10^{-27} kg. Did you ever wonder how it was possible for anyone to measure masses that small — especially to five significant digits — when there are no balances that can measure masses that small?

Atomic masses are determined by mass spectrometers, which are instruments that are based on the behaviour of moving charges in magnetic fields. The same principle causes motors to turn and prevents high-speed ions in the solar wind from bombarding Earth — except at the North and South Poles, as you read in the chapter introduction. In this section, you will learn more about moving charges in magnetic fields and many of the technologies based on this principle.

In Grade 11 physics, you were introduced to the force acting on a current-carrying conductor in a magnetic field and its application, the motor principle. The force acting on a conductor is actually due to the flow of charge through it and, in fact, the force acting on the charge is quite independent of the conductor through which the charge travels.

When a beam of charged particles is fired into a magnetic field, the following properties are observed.

- The beam will not be deflected if the direction of travel of the charges is parallel to the magnetic field.
- Maximum deflection occurs when the beam is aimed *perpendicular* to the direction of the magnetic field.
- The magnetic deflecting force is always perpendicular to *both* the direction of travel of the charge *and* the magnetic field.
- The magnitude of the magnetic deflecting force is directly proportional to the magnitude of the charge on each particle: $F_{\mathrm{M}} \propto q$.
- There is no magnetic force on a stationary charge.
- The magnitude of the force is directly proportional to the speed of the charged particles: $F_{\mathrm{M}} \propto v$.
- The magnitude of the force is directly proportional to the magnetic field intensity: $F_{\mathrm{M}} \propto B$.
- The magnitude of the force depends on the sine of the angle between the direction of motion of the charge and the applied magnetic field: $F_{\mathrm{M}} \propto \sin\theta$.

These proportional relationships can be summarized by one joint proportion statement.

$$F \propto qvB\sin\theta$$
$$F = kqvB\sin\theta$$

The definition of the unit for the magnetic field intensity, B, was chosen to make the value of the constant k equal to unity, so $F = qvB\sin\theta$. If you solve the equation for B, you can see the units that are equivalent to the unit for the magnetic field intensity.

$$B = \frac{F}{kqv\sin\theta}$$

The unit, one tesla (T), was chosen as the strength of the magnetic field. A charge of one coulomb, travelling with a speed of one metre per second perpendicular to the magnetic field ($\theta = 90^\circ$ and $\sin\theta = 1$) experiences a force of one newton. By substituting units into the equation for B and letting $k = 1$ and $\sin 90^\circ = 1$, you can find the equivalent of one tesla.

$$\text{tesla} = \frac{\text{newton}}{\text{coulomb}\frac{\text{metre}}{\text{second}}}$$

$$\text{T} = \frac{\text{N}}{\text{C}\frac{\text{m}}{\text{s}}} = \frac{\text{N}\cdot\text{s}}{\text{C}\cdot\text{m}}$$

The direction of the magnetic force on the charge q follows a right-hand rule. If you arrange your right hand so that the fingers are pointing in the direction of the magnetic field, $\vec{B}$, and the thumb is pointing in the direction of motion of a *positively* charged particle, q, then the palm of the hand points in the direction of the magnetic force, $\vec{F}_{\text{M}}$, acting on the particle.

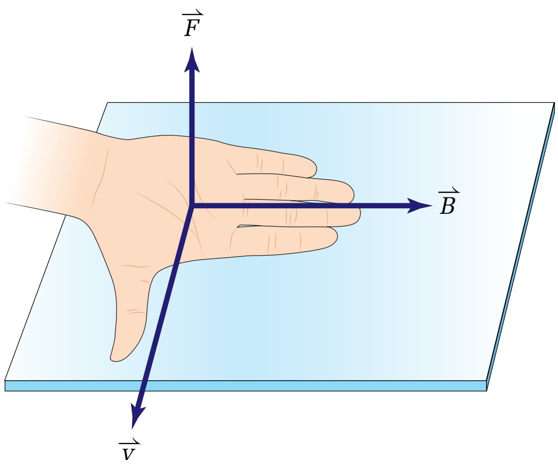


Figure 8.10 The direction of the magnetic force on the charge q follows a right-hand rule.

MATH LINK

You have probably noticed that the equation for the force on a moving charge in a magnetic field is the product of two vectors that yields another vector. In mathematics, this type of equation is called a "vector product" or "cross product" and is written $\vec{F} = q\vec{v} \times \vec{B}$. The magnitude of a vector product is equal to the product of the magnitudes of the two vectors times the sine of the angle between the vectors. The direction of the vector product is perpendicular to the plane defined by the vectors that are multiplied together.

ELECTRONIC LEARNING PARTNER

Refer to your Electronic Learning Partner to enhance your understanding of magnetic fields.

FORCE ON A MOVING CHARGE IN A MAGNETIC FIELD

The magnitude of the magnetic force exerted on a moving charge is the product of the magnitudes of the charge, the velocity, the magnetic field intensity, and the sine of the angle between the velocity and magnetic field vectors.

$$F_{\mathrm{M}} = qvB\sin\theta$$

Quantity	**Symbol**	**SI unit**
magnetic force on a moving charged particle	F_{M}	N (newtons)
electric charge on the particle	q	C (coulombs)
magnitude of the velocity of the particle (speed)	v	$\frac{\mathrm{m}}{\mathrm{s}}$ (metres per second)
magnetic field intensity	B	T (teslas)
angle between the velocity vector and the magnetic field vector	θ	degree (The sine of an angle is a number and has no units.)

Unit Analysis

$$\text{newton} = \text{coulomb}\left(\frac{\text{metre}}{\text{second}}\right)\text{tesla}$$

$$\mathrm{N} = \mathrm{C}\left(\frac{\mathrm{m}}{\mathrm{s}}\right)\mathrm{T} = \frac{\mathrm{C}\cdot\mathrm{m}\cdot\mathrm{T}}{\mathrm{s}} = \mathrm{N}$$

$\vec{F}$ is perpendicular to the plane containing $\vec{v}$ and $\vec{B}$. Since one coulomb per second is defined as an ampere ($1\ \frac{\mathrm{C}}{\mathrm{s}} = 1\ \mathrm{A}$), the tesla is often defined as $T = \frac{\mathrm{N}}{\mathrm{A}\cdot\mathrm{m}}$.

Since the vectors $\vec{F}$, $\vec{v}$, and $\vec{B}$ are never in the same plane, physicists have accepted a convention for drawing magnetic fields. As shown in Figure 8.11, a magnetic field that is perpendicular to the plane of the page is drawn as crosses or dots. The crosses represent a field directed into the page and the dots represent a field coming out of the page.

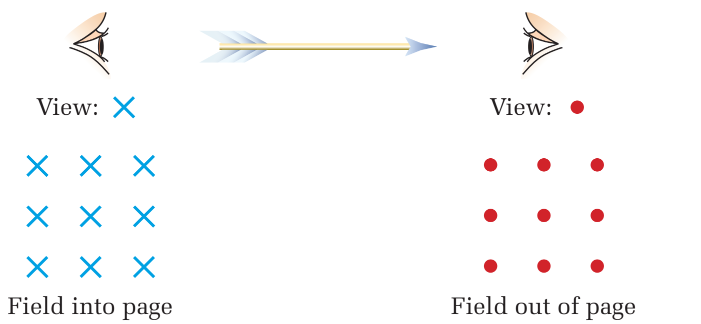


Figure 8.11 To remember the convention for drawing magnetic fields, think of the dot as the point of an arrow coming toward you. Think of the cross as the tail of the arrow going away from you.

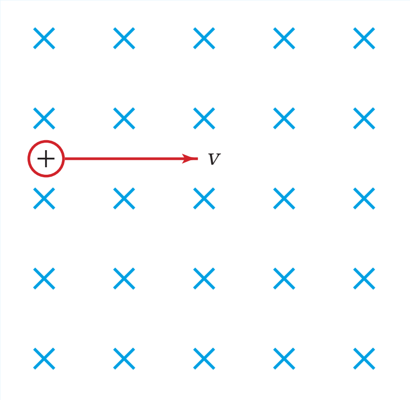
SAMPLE PROBLEM

Force on a Moving Charge

A particle carrying a charge of +2.50 μC enters a magnetic field travelling at 3.40×10^5 m/s to the right of the page. If a uniform magnetic field is pointing directly into the page and has a strength of 0.500 T, what is the magnitude and direction of the force acting on the charge as it just enters the magnetic field?

Conceptualize the Problem

- Make a sketch of the problem.
- The *charged particle* is *moving* through a *magnetic field*; therefore, it experiences a *force*.
- The *force* is always *perpendicular* to both the direction of the *velocity* and of the *magnetic field*.



Identify the Goal

The magnetic force, F_M, on the charged particle

Identify the Variables and Constants

Known	Implied	Unknown
$q = 2.50\,\mu\text{C}$	$\theta = 90^\circ$	F_M
$v = 3.40 \times 10^5\,\frac{\text{m}}{\text{s}}$		
$B = 0.500\,\text{T}$		

Develop a Strategy

Use the equation that relates the force on a charge in a magnetic field to the charge, velocity, and magnetic field intensity. Substitute numerical values and solve.

$$F_M = qvB\sin\theta$$

$$F_M = (2.50 \times 10^{-6}\,\text{C})\left(3.40 \times 10^5\,\frac{\text{m}}{\text{s}}\right)(0.500\,\text{T})(\sin 90^\circ)$$

$$F_M = 0.425\,\text{N}$$

Use the right-hand rule to determine the direction.

- Thumb represents travel of charge to the right.
- Fingers represent direction of magnetic field into the page.
- Palm represents direction of magnetic force on charge toward the top of the page.

The magnetic force on the moving charge is 4.25×10^{-1} N toward the top of the page.

Validate the Solution

A small charge combined with a high speed reasonably would produce the force calculated.

$$\cancel{\text{C}} \cdot \frac{\cancel{\text{m}}}{\cancel{\text{s}}} \cdot \frac{\text{N}\cdot\cancel{\text{s}}}{\cancel{\text{C}}\cdot\cancel{\text{m}}} = \text{N}$$

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PRACTICE PROBLEMS

12. An alpha particle, charge $+3.2 \times 10^{-19}$ C, enters a magnetic field of magnitude 0.18 T with a velocity of 2.4×10^{6} m/s to the right. If the magnetic field is directed up out of the page, what is the magnitude and direction of the magnetic force on the alpha particle?

13. A proton is projected into a magnetic field of 0.5 T directed into the page. If the proton is travelling at 3.4×10^{5} m/s in a direction [up 28° right], what is the magnitude and direction of the magnetic force on the proton?

14. An electron travelling at 6.00×10^{5} m/s enters a magnetic field of 0.800 T. If the electron experiences a magnetic force of magnitude 3.84×10^{-14} N, what was the original direction of the electron's velocity relative to the magnetic field?

15. A particle having a mass of 0.200 g has a positive charge of magnitude 4.00×10^{-6} C. If the particle is fired horizontally at 5.0×10^{4} m/s[E], what is the magnitude and direction of the magnetic field that will keep the particle moving in a horizontal direction as it passes through the field?

16. A +4.0 μC charge is projected along the positive *x*-axis with a speed of 3.0×10^{5} m/s. If the charge experiences a force of 5.0×10^{-3} N in the direction of the negative *y*-axis, what must be the magnitude and direction of the magnetic field?

The magnetic force experienced by a charged particle moving freely through a perpendicular magnetic field can be compared to the force exerted on a current-carrying conductor that also is perpendicular to the magnetic field. The net force on a conductor of length l will be the total of the individual forces acting on each charge.

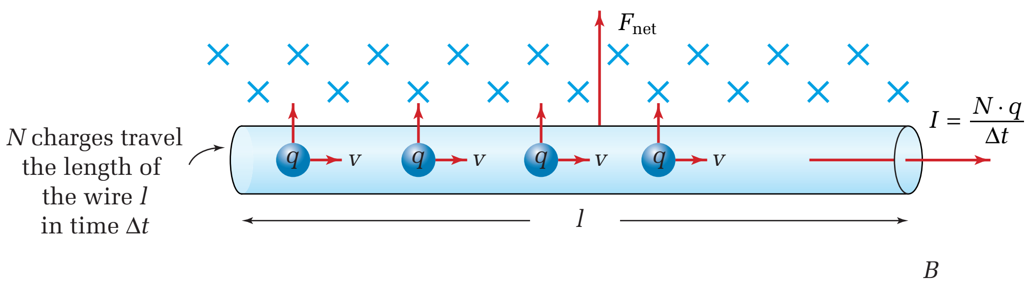

Figure 8.12 When the charges that are moving through a magnetic field are confined to a wire, the magnetic force appears to act on the wire.

If N charges, each of magnitude q, travel the distance equal to the length of the wire l in a time interval Δt, the velocity will be $l/\Delta t$. The net force will be as follows.

$$F_{net} = N \cdot qvB\sin\theta$$

$$F_{net} = N \cdot q \cdot \frac{l}{\Delta t} \cdot B\sin\theta$$

$$F_{net} = \left(\frac{N \cdot q}{\Delta t}\right) \cdot l \cdot B\sin\theta$$

$\frac{N \cdot q}{\Delta t}$ is the total charge per unit time, the current.

FORCE ON A CURRENT-CARRYING CONDUCTOR IN A MAGNETIC FIELD

The magnitude of force on a conductor carrying a current in a magnetic field is the product of the magnetic field intensity, the length of the conductor, the current in the conductor, and the sine of the angle that the electric current makes with the magnetic field vector.

$$F_{\mathrm{M}} = IlB \sin \theta$$

Quantity	**Symbol**	**SI unit**
magnetic force on a current-carrying conductor	F_M	N (newtons)
electric current in the conductor	I	A (amperes)
length of the conductor	l	m (metres)
magnetic field intensity	B	T (teslas)
angle between the conductor and the magnetic field vector	θ	degree (The sine of an angle is a number and has no units.)

Unit Analysis

$$\mathrm{T} \cdot \mathrm{A} \cdot \mathrm{m} = \frac{\mathrm{N} \cdot \cancel{\mathrm{s}}}{\cancel{\mathrm{C}} \cdot \cancel{\mathrm{m}}} \cdot \frac{\cancel{\mathrm{C}}}{\cancel{\mathrm{s}}} \cdot \cancel{\mathrm{m}} = \mathrm{N}$$

Although many of the quantities in the equation for the magnetic force on a current-carrying wire are vectors, the equation can be used only to determine the magnitude of the force, so the vector notation has not been used. Directions must be determined by the relevant right-hand rules. $\vec{F}_{\mathrm{M}}$ is perpendicular to the plane containing $\vec{v}$ and $\vec{B}$. The right-hand rule for the direction of the force is shown in Figure 8.13.

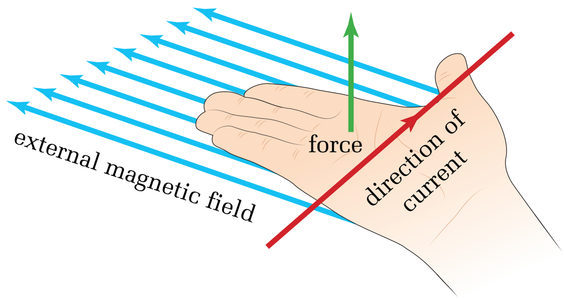

Figure 8.13 The thumb points in the direction of the current, the fingers point in the direction of the magnetic field vector, and the palm of the hand indicates the direction of the force on the conductor.

SAMPLE PROBLEM

Force on a Current-Carrying Conductor

A wire segment of length 40.0 cm, carrying a current of 12.0 A, crosses a magnetic field of 0.75 T[up] at an angle of [up 40° right]. What magnetic force is exerted on the wire?

Conceptualize the Problem

- *Charges* in the wire are *moving* through a *magnetic field*.
- *Moving charges* in a *magnetic field* experience a *force*.
- The *magnetic force* is related directly to the *magnetic field intensity*, the *electric current*, the *length* of the wire segment, and the *angle* between the wire and the magnetic field.

Identify the Goal

The magnetic force, F_M, on the wire segment

Identify the Variables and Constants

Known	Unknown
$l = 40.0\text{ cm}$	F_M
$I = 12.0\text{ A}$	
$B = 0.75\text{ T}$	
$\theta = 40^\circ$ between B and I	

Develop a Strategy

Find the force using the relevant equation that relates force, magnetic field, current, and length of wire that is in the field.

$$F = IlB\sin\theta$$
$$F = (12.0\ A)(0.40\ m)(0.75\text{ T})(\sin 40^\circ)$$
$$F = 2.3140\text{ N}$$
$$F \cong 2.3\text{ N}$$

Determine the direction using the right-hand rule; only the [right] component of the current, perpendicular to the magnetic field direction, contributes to the magnetic force.

- Thumb of right hand points right
- Fingers point up toward top of page

The force will be out of the page, according to the right-hand rule.

- Palm will be facing up out of the page

The force of the magnetic field on the conductor is 2.3 N[out of the page].

Validate the Solution

The force seems to be consistent with the magnetic field and current values. The direction is consistent with the right-hand rule.

$$\text{T}\cdot\text{A}\cdot\text{m} = \frac{\text{N}}{\cancel{\text{A}}\cdot\cancel{\text{m}}}\cdot\cancel{\text{A}}\cdot\cancel{\text{m}} = \text{N}$$

PRACTICE PROBLEMS

17. A wire 82.0 m long runs perpendicular to a magnetic field of strength 0.20 T. If a current of 18 A flows in the wire, what is the magnitude of the force of the magnetic field on the wire?

18. A wire 65 cm long carries a current of 20.0 A, running east through a uniform magnetic field. If the wire experiences a force of 1.2 N[N], what is the magnitude and direction of the magnetic field?

19. A segment of conducting wire runs perpendicular to a magnetic field of 2.2×10^{-2} T. When the wire carries a current of 15 A, it experiences a force of 0.60 N. What is the length of the wire segment?

20. **(a)** What current would need to flow east along the equator through a wire 5.0 m long, which weighs 0.20 N, if the magnetic field of Earth is to hold the wire up against the force of gravity? (Assume that Earth's horizontal magnetic field intensity at this location is 6.2×10^{-5} T.)

 (b) Discuss the practicality of this result.

Circular Motion Caused by a Magnetic Field

When a charge enters a magnetic field at right angles, the resulting magnetic force on the particle is perpendicular to both the velocity vector and the magnetic field vector. Consequently, there is no component of the force in the direction of motion and the speed will not change. As the charge is deflected by the force, it still remains perpendicular to the magnetic field. This means that it will always experience a constant magnitude of force *perpendicular* to its motion. This is the standard requirement for circular motion at constant speed. The magnetic force is providing the centripetal force on the particle.

$$qvB = \frac{mv^2}{r}$$

$$r = \frac{mv^{\cancel{2}}}{q\cancel{v}B}$$

$$r = \frac{mv}{qB}$$

Motion Due to Both Electric and Magnetic Fields

You have now studied ways in which electric and magnetic fields can exert forces on a charged particle. The following are examples in which both types of field affect the motion of a particle.

Simple Particle Accelerator

A simple **particle accelerator** consists of a particle source, a pair of parallel plates, and an accelerating potential difference. The particle source can be simply a spark gap that causes the surrounding gas molecule to become ionized, that is, separate into positive and negative particles. These "ions" then enter the region

COURSE CHALLENGE

Field Energy

A book falls from your desk, a movie plays on a television screen, and a homing pigeon can find its way home, all because of the energy within a field. Refer to page 604 of this textbook for suggestions relating field energy to your Course Challenge.

between the parallel plates and are accelerated by the potential difference between the plates. A hole in the opposite plate allows the particles to continue into the region beyond the plates. For this reason the apparatus is sometimes called a "particle gun," or in the case of electrons, an "electron gun." As a result, the kinetic energy of the emerging particles can be expressed in terms of the work done on them between the parallel plates: $\frac{1}{2}mv^2 = qV$.

Velocity Selector

A velocity selector is a device quite often associated with the parallel plate particle accelerator. A beam of particles having different velocities, as a result of carrying different charges, is "filtered" so that only those particles with the same velocity continue. The apparatus consists of a crossed (perpendicular) electric and magnetic field. A positively charged particle, for example, would experience an upward force due to the magnetic field and a downward force due to the electric field. If the two forces are equal, the particle will travel straight through the velocity selector.

You can determine the velocity of particles that will pass directly through the velocity selector by taking the following steps.

- Set the electric and magnetic forces equal to each other. $F_M = F_Q$
- Write the expressions for the two forces. $F_M = qvB$, $F_Q = qE$
- Substitute the expressions for the values of the forces into the first equation. $qvB = qE$
- Solve for the velocity.

$$v = \frac{\cancel{q}E}{\cancel{q}B}$$

$$v = \frac{E}{B}$$

Only charged particles with a velocity that matches the ratio of the electric field intensity to the magnetic field intensity will continue to travel in a straight line. Particles with other speeds will be deflected up or down and absorbed by the surrounding material.

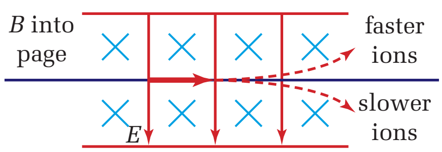

Figure 8.14 Only charges having one specific velocity will travel in a straight line. All others will be diverted up or down.

Mass Spectrometer

The **mass spectrometer** is an instrument that can separate particles of different mass and, in fact, measure that mass. The first stage of a mass spectrometer is a velocity selector. Then, ions of the selected speed enter a magnetic field in a direction perpendicular to the field. While in the magnetic field, the ions experience a magnetic force that is always perpendicular to the direction of their motion.

You will recognize this type of force as a centripetal force. You can see how the mass spectrometer separates particles of different masses by analyzing the following steps.

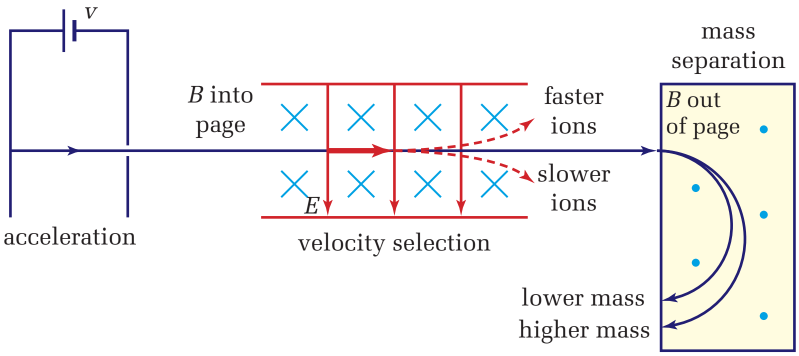

Figure 8.15 The path of positive ions through the acceleration, velocity selection, and mass separation process

- The magnetic field supplies the centripetal force. $F_C = F_M$
- Substitute the expressions for centripetal and magnetic forces. $\dfrac{mv^2}{r} = qvB$
- Solve for m. $m = \dfrac{rq\cancel{v}B}{v^{\cancel{2}}}$

$$m = \frac{rqB}{v}$$

The velocity of the particles is known because it was selected before the particles entered the magnetic field. The charge is known due to the method of creating ions that entered the velocity selector. The instrument measures the radius of the circular path. The only unknown quantity is the mass.

By observing the radius for particles of known charge, the mass can be determined. This is particularly useful for determining the relative proportions of "isotopes," atoms that have the same number of protons but different numbers of neutrons.

PHYSICS FILE

Portable mass spectrometers are used at airports and in other areas where security is a priority, in an attempt to detect particles associated with materials used in manufacturing explosives.

SAMPLE PROBLEM

Mass Spectrometer

A positive ion, having a charge of 3.20×10^{-19} C, enters at the extreme left of the parallel plate assembly associated with the velocity selector and mass spectrometer shown in Figure 8.15.

(a) If the potential difference across the simple accelerator is 1.20×10^{3} V, what is the kinetic energy of the particle as it leaves through the hole in the right plate?

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(b) The parallel plates of the velocity selector are separated by 12.0 mm and have an electric potential difference across them of 360.0 V. If a magnetic field of strength 0.100 T is applied at right angles to the electric field, what is the speed of the particles that will be "selected" to pass on to the mass spectrometer?

(c) When these particles then enter the mass spectrometer, which shares a magnetic field with the velocity selector, the radius of the resulting circular path followed by the particles is 6.26 cm. What is the mass of the charged particles?

(d) What is the nature of the particles?

Conceptualize the Problem

- When the *charged* particles enter the *electric field*, the field does *work* on the particles, giving them *kinetic energy*.
- When the *moving* particles pass through the crossed *electric* and *magnetic* fields, only those of *one specific velocity* pass through undeflected.
- When the selected particles enter the *magnetic field*, the magnetic force provides a *centripetal force*.

Identify the Goal

(a) The kinetic energy, E_k, of the particle

(b) The speed, v, of the particles that will be "selected"

(c) The mass, m, of the charged particles

(d) The nature of the particles

Identify the Variables and Constants

Known		Unknown
$q = 3.20 \times 10^{-19}$ C	$\Delta d = 12.0$ mm	E_k
$V_1 = 1.20 \times 10^3$ V	$B = 0.100$ T	v
$V_S = 360.0$ V	$r = 6.26$ cm	m

Develop a Strategy

The energy of a charged particle is related to the accelerating potential difference.

$$E_k = qV$$
$$E_k = (3.20 \times 10^{-19}\ \text{C})(1.2 \times 10^3\ \text{V})$$
$$E_k = 3.84 \times 10^{-16}\ \text{J}$$

(a) The kinetic energy of the particle was 3.84×10^{-16} J.

The selected velocity is related to the electric and magnetic fields. The electric field is related to the potential difference and the distance of separation of the plates.

$$E = \frac{V}{\Delta d} = \frac{360.0\ \text{V}}{1.20 \times 10^{-2}\ \text{m}} = 3.00 \times 10^4\ \frac{\text{N}}{\text{C}}$$
$$v = \frac{E}{B} = \frac{3.00 \times 10^4\ \frac{\text{N}}{\text{C}}}{0.100\ \text{T}}$$
$$v = 3.00 \times 10^5\ \text{m/s}$$

(b) The speed of the particles was 3.00×10^5 m/s.

The mass of the particle is related to the charge, magnetic field, radius of path, and speed.

$$m = \frac{qBr}{v}$$

$$m = \frac{(3.20 \times 10^{-19}\ \text{C})(0.100\ \text{T})(6.26 \times 10^{-2}\ \text{m})}{3.00 \times 10^{5}\frac{\text{m}}{\text{s}}}$$

$$m = 6.68 \times 10^{-27}\ \text{kg}$$

(c) The mass of the particles was 6.68×10^{-27} kg.

The charge is two times the charge on a proton. The mass is four times the mass of a proton. The particle seems to be an alpha particle, which is the positive nucleus of a helium atom.

(d) The particles seem to be alpha particles.

Validate the Solution.

The mass is what you would expect for a small atom. The units cancel to give kg, which is correct.

$$\frac{\text{C} \cdot \text{T} \cdot \text{m}}{\frac{\text{m}}{\text{s}}} = \cancel{\text{C}} \cdot \frac{\text{N} \cdot \text{s}}{\cancel{\text{C}} \cdot \cancel{\text{m}}} \cdot \cancel{\text{m}} \cdot \frac{\text{s}}{\text{m}} = \frac{\text{N} \cdot \text{s}^2}{\text{m}} = \frac{\text{kg} \cdot \cancel{\text{m}}}{\cancel{\text{s}^2}} \cdot \frac{\cancel{\text{s}^2}}{\cancel{\text{m}}} = \text{kg}$$

PRACTICE PROBLEMS

21. A proton is accelerated across parallel plates, through a potential difference of 180.0 V. Calculate

(a) the final kinetic energy of the proton

(b) the final velocity of the proton, assuming its mass is 1.67×10^{-27} kg

22. A particle of mass 1.2 g and charge +3.0 μC is held suspended against the force of gravity between a parallel pair of plates that are 15.0 mm apart.

(a) In which direction does the electric field vector point?

(b) What is the magnitude of the electric potential difference connected across the plates?

23. An isotope of hydrogen having a proton and a neutron in its nucleus is ionized and the resulting positive ion (deuteron) travels in a circular path of radius 36.0 cm in a perpendicular magnetic field of strength 0.80 T.

(a) Calculate the speed of the deuteron.

(b) What was the accelerating potential that gave the deuteron this speed?

24. An electron of mass 9.11×10^{-31} kg travels perpendicularly through a magnetic field of strength 6.8×10^{-5} T at a speed of 3.4×10^{5} m/s. What is the radius of the path of the electron?

25. What is the speed of a beam of electrons if in passing through a 0.80 T magnetic field they remain undeflected, due to a balancing electric field of 5.4×10^{3} N/C?

26. An isotope of hydrogen passes, without deflection, through a velocity selector that has an electric field of 2.40×10^{5} N/C and a magnetic field of 0.400 T. It then enters a mass spectrometer that has an applied magnetic field of 0.494 T and consequently describes a circular path with a radius of 3.80 cm.

(a) What is the mass of the particle?

(b) Which isotope of hydrogen is it?